Color Vision Deficiency in Pilots: Implications for Design

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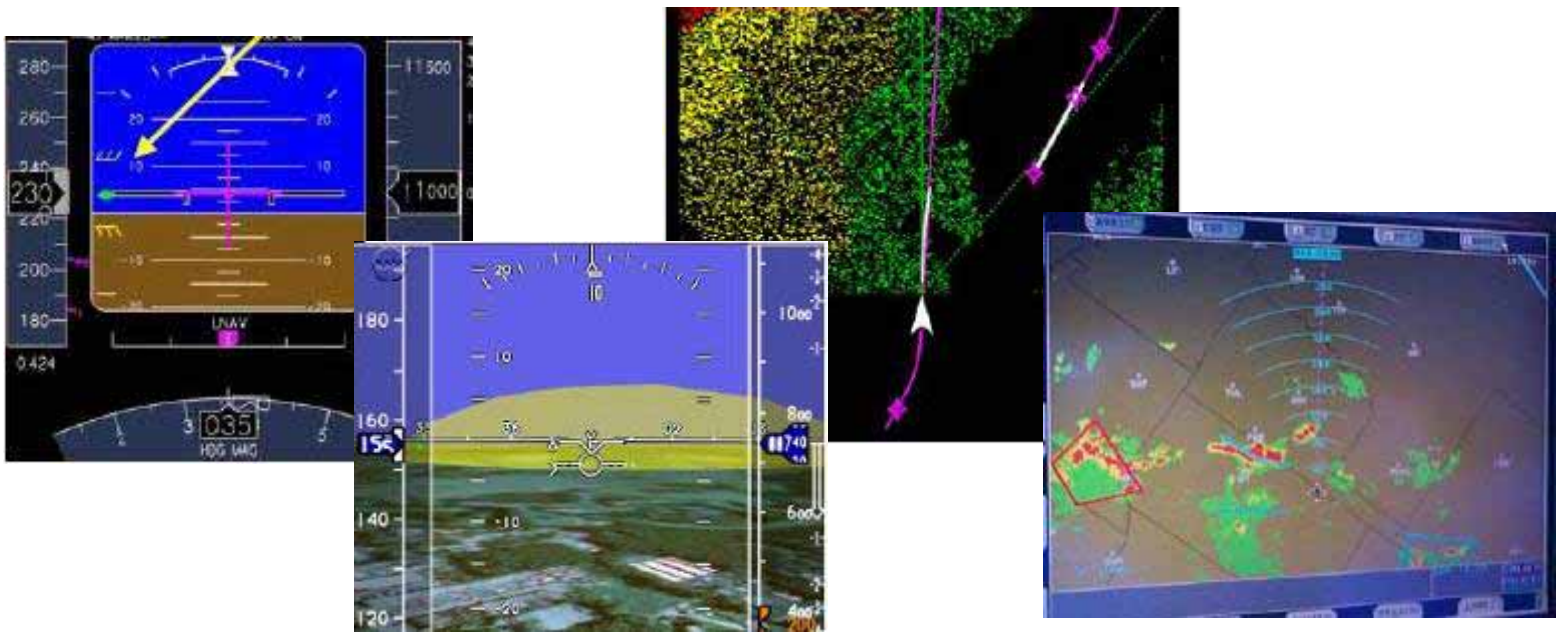
The Problem

- **Use of color in aviation**
  - Runway signal lights
  - Fuel types
  - Charts
  - **Displays** – increasing reliance on colors in complex display formats

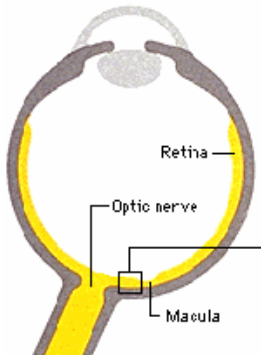


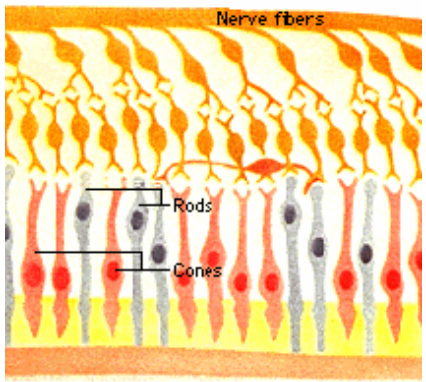
- **Pilots with color vision deficiencies**

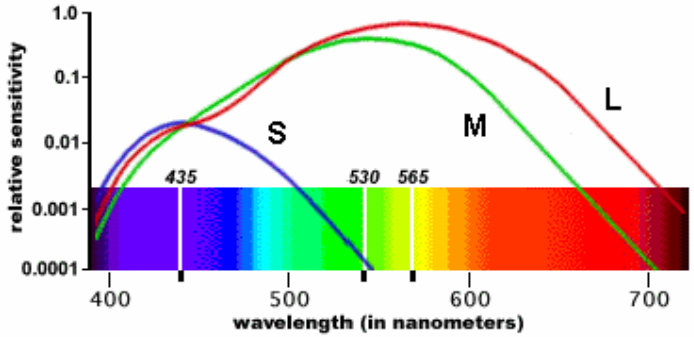
What is “Color Blindness?”

- **“Color deficiency” is more accurate.**

- **Retinal cone receptors respond to different wavelengths of light** Long, Middle**, and** Short**.**





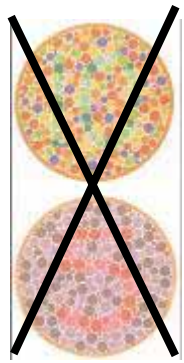


- **Color deficiencies result from the** absence **(..opia) or** altered sensitivity **(…anomaly) of cone receptors.**
  - Deuteranope (a form of red/green color deficit) – *most common*
  - Protanope (another form of red/green color deficit)
  - Tritanope (a blue/yellow deficit- very rare)

“Color Deficiency” according to the FAA

- **A pilot must have** "the ability to perceive those colors necessary for the safe performance of airman duties" **for all medical certification classes. Color vision is essential for recognizing aircraft position lights, light-gun signals, airport beacons, approach-slope indicators, and chart symbols, especially at night.”** ***(14 CFR Part 67 revised 9/16/96)***

- **If you fail, your medical certificate may have the limitation:**
  - “not valid for night flying or by color signal control.”



But don’t worry!

- **Guidance for improving your odds..**

  “If possible, ***find an optometrist or ophthalmologist who uses the Dvorine*** *or AOC test plates. People with color vision deficiencies usually find these easier to pass than the Ishihara plates.” (http://www.leftseat.com/falant.htm 8/29/05)*

- **You can request reevaluation or a SODA, usually requiring a signal light or flight test (14 CFR 67.401).**

  “The high success rate of the light gun signal test among individuals who have previously failed another FAA-acceptable color vision screening test (~95%) suggests that ***this test may not identify all the individuals with severe color deficiencies that could affect their ability to safely operate an aircraft*** *(NTSB Recommendation A-04-46,-47, 6/10/2004).”*

How many are there?

Medical Certificates	First Class		Second Class		Third Class	
	Male	Female	Male	Female	Male	Female
Airmen with restriction for color vision deficiency	273	0	786	1	5,415	19
Airmen with waiver for color vision deficiency	2,044	0	3,076	8	4,899	19
Total airmen with color vision deficiency	2,317	0	3,862	9	10,314	38

16,540 airmen with IDENTIFIED color vision deficiencies.

(Aeromedical Certification Statistical Handbook, 1998)

That's an underestimate!

- **Pilots taking easier tests to pass**

- **Temporary / evolving influences on color vision**
  - ***Diseases***: inflammation of the optic nerve, glaucoma, cataracts, multiple sclerosis, central serous retinopathy, cataracts …
  - ***Drugs***: viagra, some cardiac medications, some antibiotics, malaria preventing drugs, diuretics, barbiturates …
  - ***Aging*** – yellowing of lens, nature's "blue blocker"
  - ***Sunglasses*** – blue blockers are worst, grey is recommended

- **Increasing accessibility to wider population**
  - approximately 8% of men and 0.4% of women

Does it ever really make a difference?

- Aircraft Accident Report number NTSB/AAR-04/02.

  On July 26, 2002, at 0537 eastern daylight time, a FedEx Boeing 727, N497FE, crashed during landing at Tallahassee, Florida. The airplane crashed short of the runway, and was destroyed by fire. All three crewmembers were seriously injured.

  The NTSB determines the probable cause(s) of this accident as follows:

  The captain's and first officer's failure to establish and maintain a proper glidepath during the night visual approach to landing. Contributing to the accident was a combination of the captain's and first officer's fatigue, the captain's and first officer's failure to adhere to company flight procedures, the captain's and engineer's failure to monitor the approach, and the first officer's color vision deficiency for interpreting signal lights.

- National Transportation Safety Board Incident Report – July 1992

  The pilot was wearing blue blocking sunglasses that made him unable to see the blue light coming from the engine anti-ice light system [9]. These sunglasses altered this pilot's vision in a way similar to how *(some)* color deficient pilots perceive.

  Nakagawara, V.B., Montgomery, Ron. W, Wood, Kathryn J., Aviation Accidents and Incidents Associated With the Use of Ophthalmic Devices by Civilian Pilots. 2001, Civil Aerospace Medical Institute.

Color Guidance for Flightdeck Design

- **Airworthiness standards for flightdeck lights** ***(FAA 14 p23.1311)***
  - **Red** for hazardous conditions requiring immediate action.
  - Yellow for marginal conditions/caution upcoming danger.
  - Green indicates that the conditions are satisfactory.
  - **White** indicates alternative functions as needed.
  - Blue is used for advisories.

- **FAA's Human Factor's Design Guidelines** ***(FAA, 1996)***
  - Use color **consistently within its application**
  - Consistent with the **users' expectations**
  - **Distinguishable** and **distinct** hues

- **Design guidance for color-deficient users**
  - Relative **sensitivities to hues**
  - **Contrast** cues
  - **Redundant coding**, e.g., shape

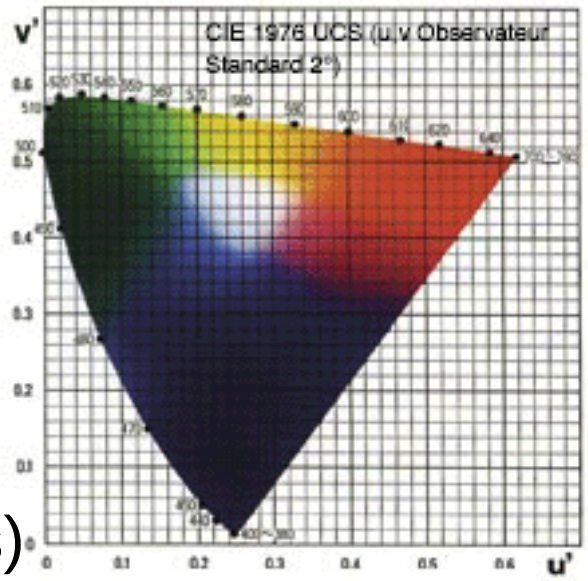
The Investigation

- **Analytical & Heuristic Assessments**

- **Empirical assessment**
  - METAR symbols
  - “At-a-Glance” methodology

Analytical Assessments

- **Contrast Ratio >= 0.1 (MIL-HDBK-87213)**
  - Luminance data for target (Lt) and background (Lb)
  - Contrast modulation = (Lt –Lb)/(Lt+Lb), [0,1]



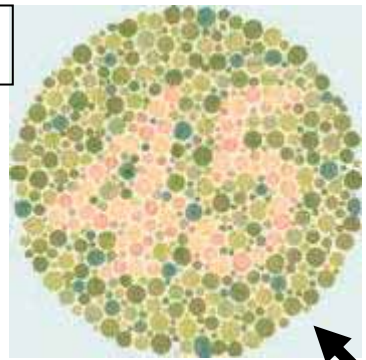
- **Color discriminability**
  - CEILUV76 (tristimus color coordinates)
  - Identified color pallets with low color differences (< 30) that pilots could have difficulty distinguishing

Heuristic Assessments

- **Semantic associations**
- **Perceptual Simulations ~ Vischeck**
- **"Daltonization" enhanced for Red/Green deficiency**

1

Original full-color image



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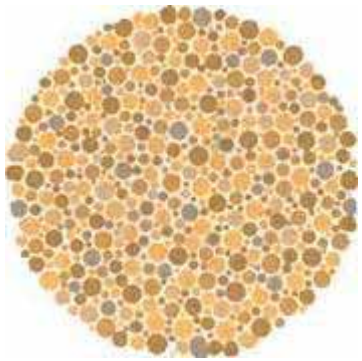
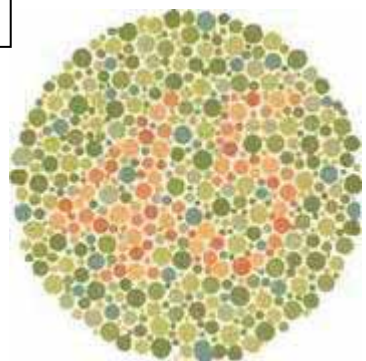


Deuteranopic Simulation of [1]

3

Daltonized image [1]



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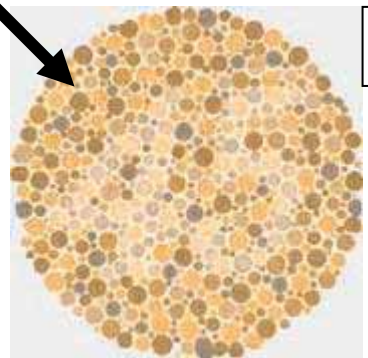
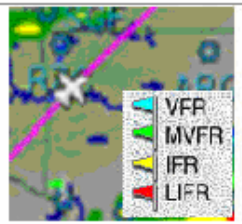
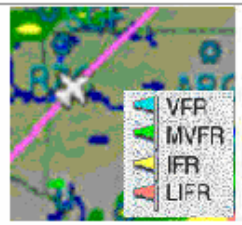
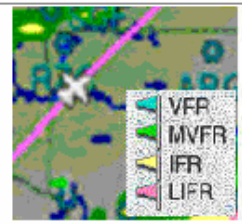
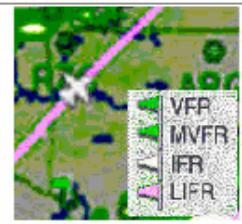
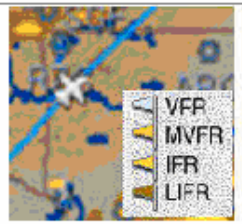
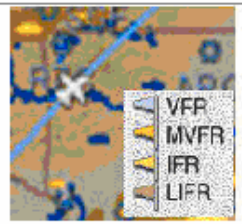
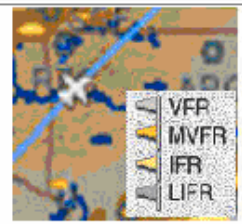
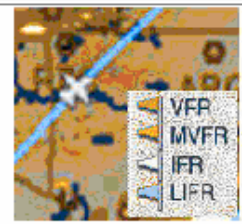


Deuteranopic Simulation of [2]

Application to METAR Codes

Original	Low Daltonization	Medium Daltonization	High Daltonization
 Avidyne	 Avidyne	 Avidyne	 Avidyne
Deuteranope version of original	Deuteranope version of Daltonized image	Deuteranope version of Daltonized image	Deuteranope version of Daltonized image
 Avidyne	 Avidyne	 Avidyne	 Avidyne

Unfortunately…

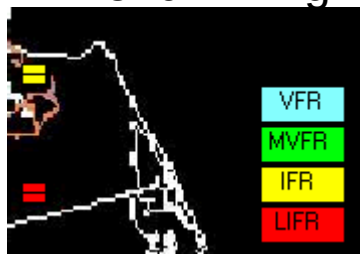
- **Daltonizing existing formats creates indistinct codings**
- **Violates semantic codings**

….. But the idea of a transformation design tool is a good one!

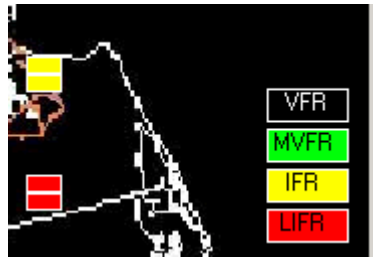
Empirical Assessment

- **Conditions**

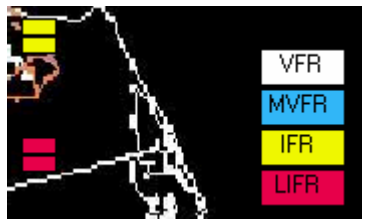
1. Bendix-King



2. ARNAV



3. New Color Scale



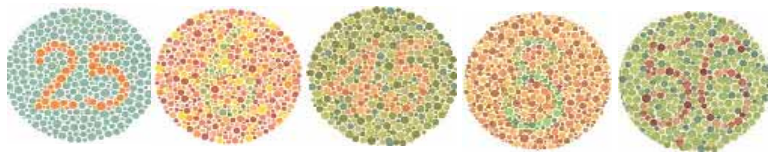
4. New Gray Scale

  - 4 category levels
  - Targets superimposed on NEXRAD backgrounds of 4 levels.

- **Subjects**
  - 17 subjects, tested by Ishihara 24 plate color vision test
  - 11 normals, 6 red/green deficient

Experiment

- **Pretest**
  - Ishihara 24 plate color vision test

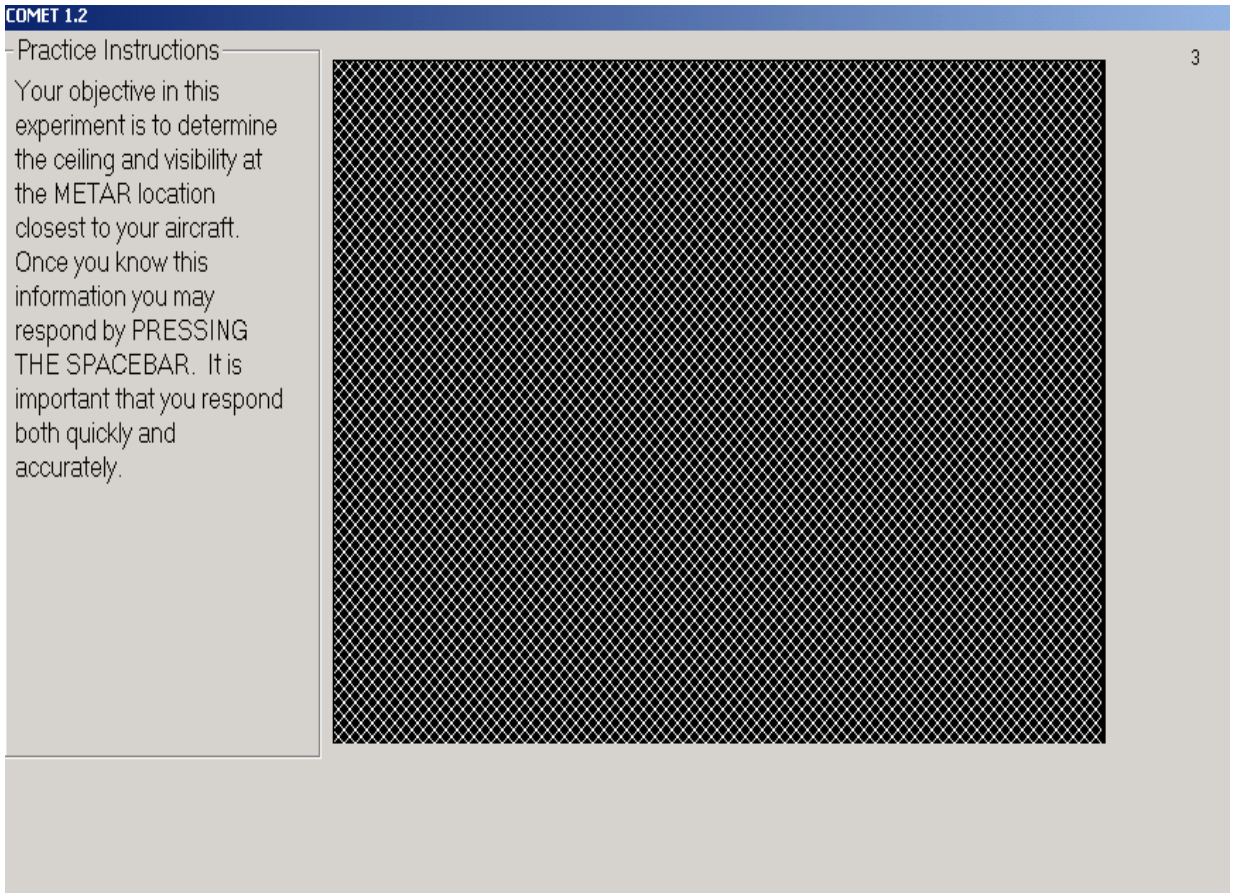


- **Apparatus**
  - Laptop in booth

- **Trials, for each condition (counterbalanced blocks)**
  - Training with feedback (8 trials)
  - Practice (10 trials)
  - Data (16 trials)

- **Debriefing**
  - Preference questionnaire
  - Experimental conditions questionnaire

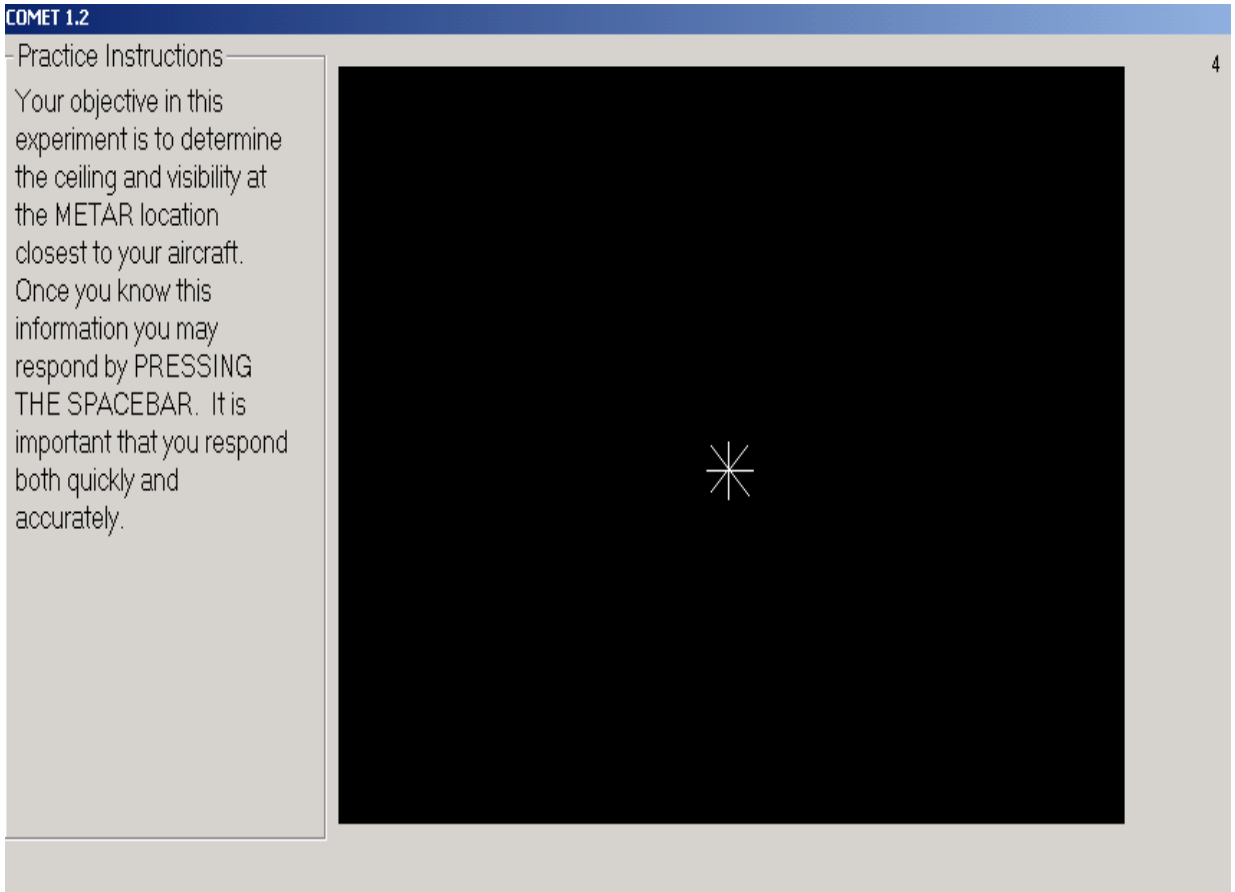
Masking Screen



800ms

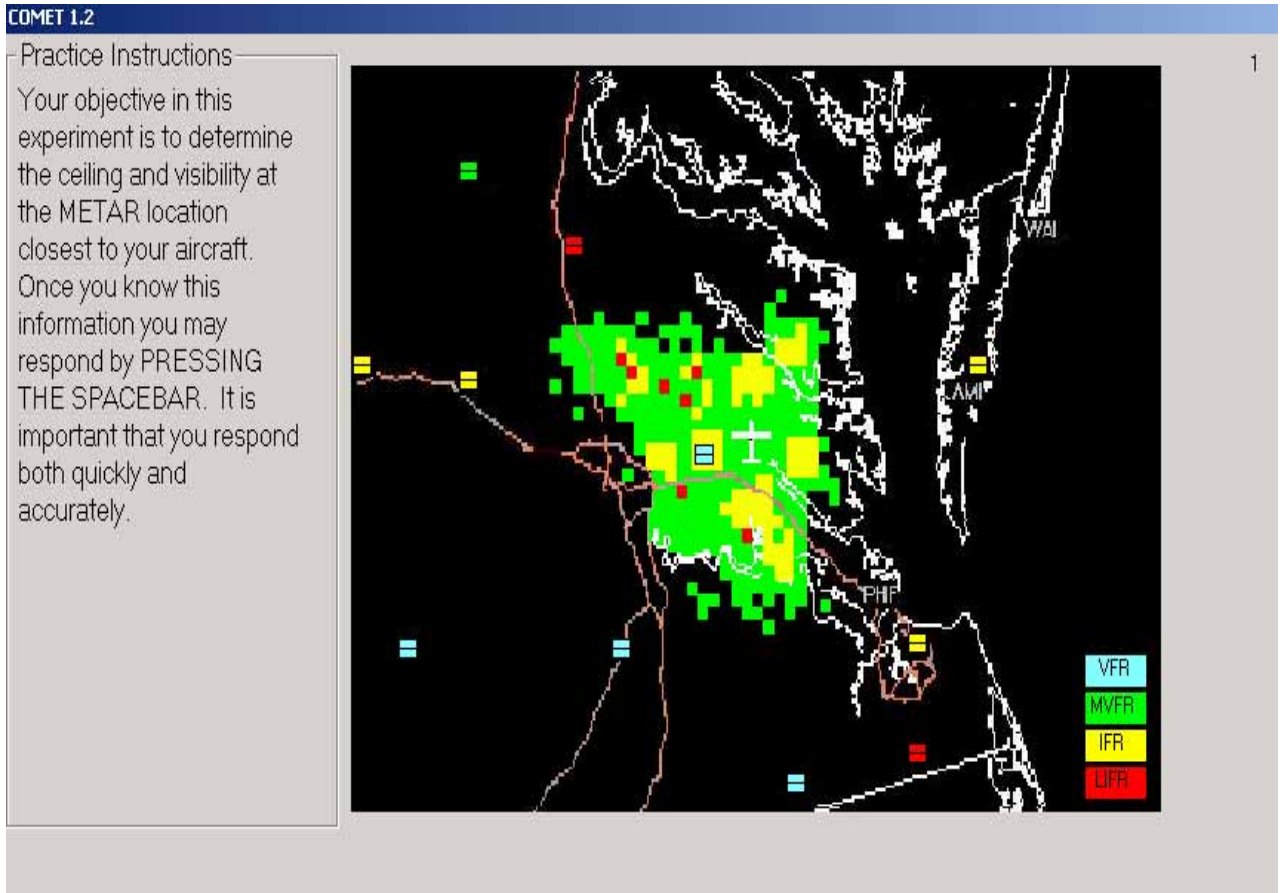
Cueing Screen

150 ms blank screen



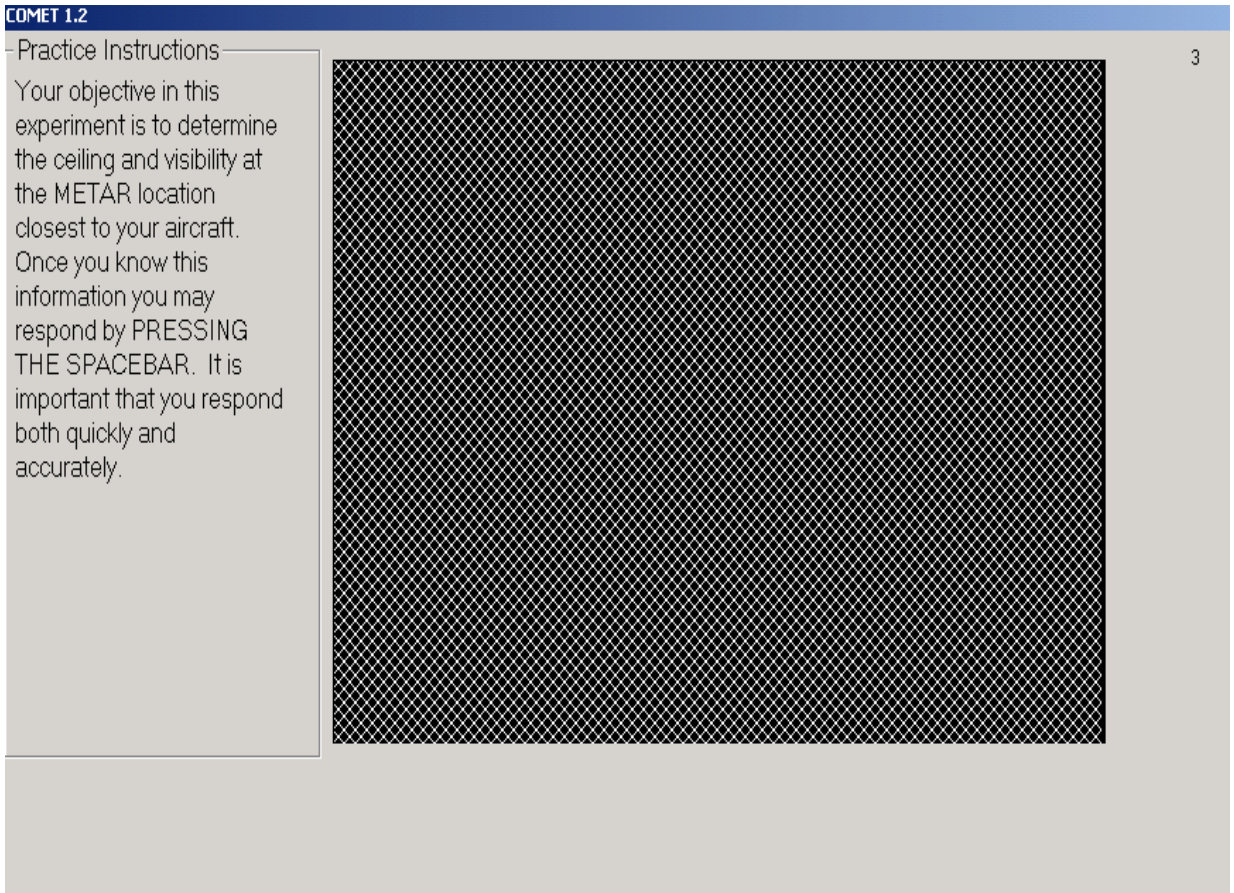
250ms

Stimulus Screen



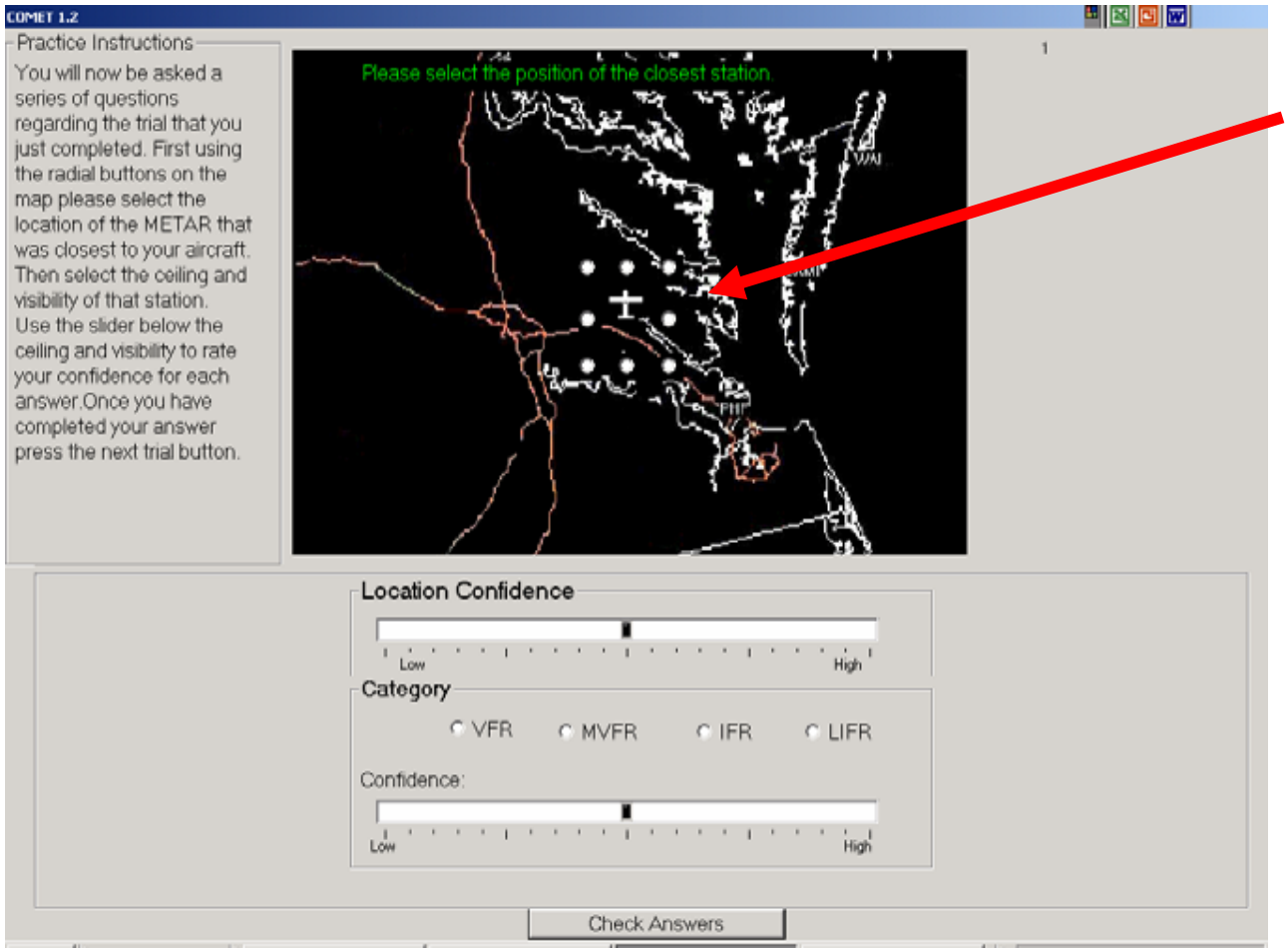
"Respond by pressing the spacebar.
It is important that you respond both quickly and accurately"

Masking Screen



800ms

Response Screen



1) **Pick the direction of closest METAR**

2) ***Confidence in direction***

3) **Identify category**

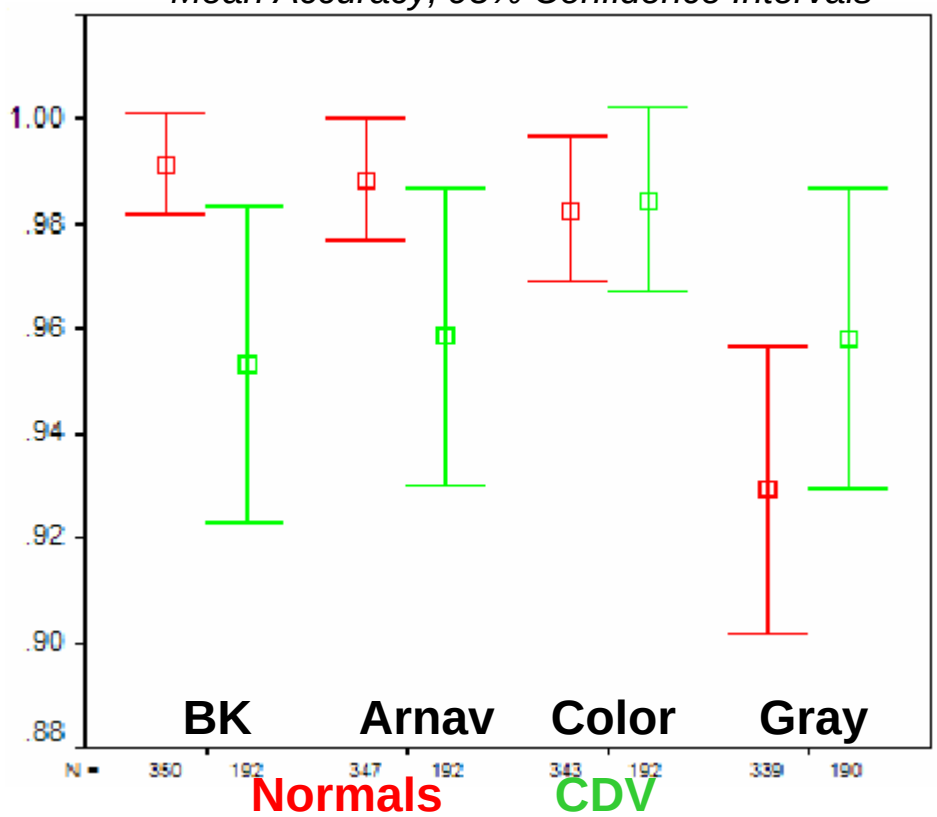
4) ***Confidence in category***

Results

- **Location Errors**
  - Few (< 10% in worst condition, “gray”)
  - No significant effect of color vision
  - *These data removed for subsequent analyses*

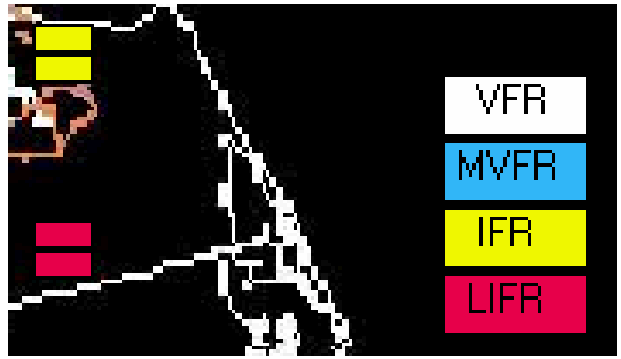
- **Category Errors**
  - Color deficiency effect
  - “New Color” mitigates
  - “Gray” CDV sensitivity

Mean Accuracy, 95% Confidence Intervals



Preference Questionnaire

- **METAR symbol interpretation**
  - **Modified color is most preferred**
    - All color deficient subjects (6/6)
    - All but 2 normals (9/11)
  - ***Gray scale is least preferred***
    - All but 1 color deficient, all but 2 normals



- **NEXRAD level interpretation**
  - **No clear preference** for either subject group
  - Clearly ***gray scale least preferred*** (all color deficient, 9/11 normals)

- **Preferences consistent with performance data !**

Demonstration of Assessment Methods

- **Analytical assessments**
  - **Contrast** modulation calculations
  - CIELUV **color difference** calculations

- **Heuristic assessments**
  - **Guidelines**
    - Perception: Exogenous attention capture
    - Cognition: Semantics of color & social norms
    - Consistency within Context
    - Color pallets *(http://www.btplc.com/age_disability/ClearerInformation/Colours/PalFiles.htm)*
  - **Simulations** of color deficient vision (http://www.vischeck.com)

- **Empirical assessment**
  - "At-a-Glance" Methodology
  - ***Modified color design shows a potential solution***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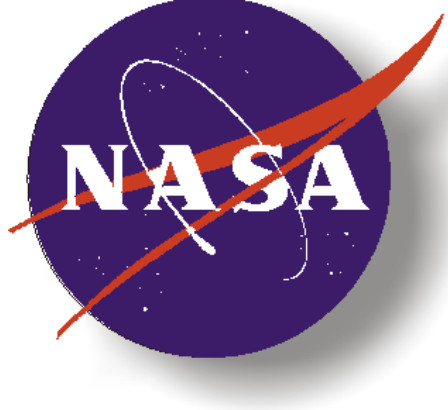
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Questions..

Extra

The recently (November 99) FDA approved ColorMax glasses are also used to enhance color discrimination in color weak individuals. The glasses were featured in the January 4, 2000 USA Today (page 8D). These glasses essentially use color reflecting coatings to alter color perception and enhance discrimination in weak color frequencies. Because other colors may altered as well, and the deficiency is not completely corrected, the FAA has not approved these glasses for color deficient pilots.